

Relationships Between Soil Salinity, Sap-Sugar Concentration, and Health of Declining Roadside Sugar Maples (*Acer saccharum*)¹

GRAHAM T. HERRICK², University School, Chagrin Falls, OH 44022

ABSTRACT. A study of 50 sugar maples (*Acer saccharum*) along Gates Mills Boulevard in Gates Mills, Ohio, showed that a tree's sap-sugar concentration tended to increase with decreasing tree health and increasing soil salt concentration. Relative tree health was determined by growth ring analysis. Salt concentration in soil was determined by measuring soil extract conductivity. Extract conductivity correlated positively with the concentration of road deicing salts in the snow in winter.

OHIO J. SCI. 88 (5): 192-194, 1988

INTRODUCTION

Many scientists have observed sugar maple decline throughout the tree's North American range during this century (Westing 1966). Decline symptoms include dieback at the top of the crown and tips of the branches, chlorosis and leaf burns, and early autumn coloration. Decline of roadside maples has been attributed to the various effects of road deicing salts (Holmes 1961, Lacasse and Rich 1964, Holmes and Baker 1966, Wester and Cohen 1968, Westing 1969, Shortle and Rich 1970, Shortle et al. 1972, Guttay 1976). Deicing salts enter soil when snow melts in spring, and can percolate into soil even when the ground is frozen in winter (Stockeller and Weitzman 1960). Salt in soil inhibits plant water uptake by raising the osmotic pressure of soil water (Prior and Berthouex 1967). Sap-sugar concentration increases with a reduction in water uptake (Cortes and Sinclair 1985, Milburn and Zimmerman 1986). Accordingly, the sugar concentration of the sap should be affected by road salt application. The purpose of this study was to determine relationships between sap-sugar concentration, decline of the trees, and salinity of the surrounding soil.

METHODS AND MATERIALS

SITE CHARACTERISTICS. The study was done on 50 sugar maples (*Acer saccharum*) located on the dividing island of Gates Mills Boulevard, a four-lane divided boulevard in the village of Gates Mills, Ohio (Fig. 1). The trees are spaced 15.2 m apart and are 4.9 m from the eastbound lane. They were planted at the same time from the same nursery stock and are all the same age (G. Pasuit, pers. comm.). There is a traffic circle at the west end of the study site where SR 91 intersects the village boulevard.

TREE HEALTH ASSESSMENT. Core samples were taken from each tree 1.4 m (breast height) above the base using an increment borer. Growth rings from 1977 to 1986 were measured with a standard architectural rule under a binocular microscope. To find an index of health, the incremental radial growth of each tree for each year from 1982 to 1986 was standardized by converting to the number of standard deviations from the mean incremental growth of all trees for that year. Each tree then had five standardized values which were averaged to give an index for that tree. By creating this index, any meteorological effects influencing the entire population were removed from individual tree health ratings. A preliminary analysis determined that the most statistically significant decline in annual ring width occurred from 1982-1986; so only those values were used in the tree health index.

SAP-SUGAR CONCENTRATION. All 50 trees were tapped with plastic spiles as is done in commercial maple syrup production.

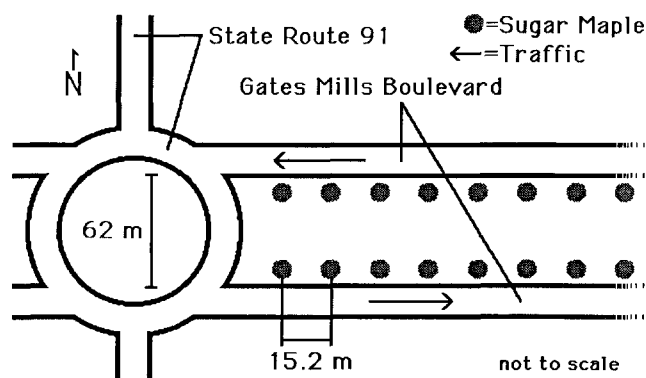


FIGURE 1. Map of the west end of the study site. Maples in the study were next to the eastbound lane of the boulevard.

Short pieces of plastic tubing were connected to the spiles, and the tubing was squeezed shut with wooden clamps to prevent sap exudation when samples were not being taken. Measurements of percent sugar in the sap were taken at each tree on 24 February, 7 March, 16 March, and 18 March, 1987 with a hand-held refractometer. The sap was drained from the tube and spile for at least 15 min before sampling to get fresh sap. The measurements were done between 1300 and 1500 h. There was never a lag of more than 1 h between the first and last samples of each day.

TESTS OF APPLIED SALT. Snow samples were taken at locations 30 to 60 cm away from the boulevard adjacent to each tree. Fifty milliliters of melted snow were filtered, dried, and then weighed to find the concentration of total dissolved solids. Snow samples were also taken 30.5 m from the boulevard (the middle of the island) as a reference.

SOIL TESTS. Soil cores were taken in mid-May at 50 sites halfway between each tree and the boulevard. At each site, three cores were taken within 30 cm of each other. Additional soil samples were taken 30.5 m from the boulevard as a reference. Because a preliminary sampling of 11 sites along the boulevard demonstrated that the maximum concentration of salts occurred in the top 2 cm of the soil, the top 2 cm from each of the three cores at each site were mixed, dried, ground, and sifted through a 1-mm screen. Solutions were extracted (20 mL distilled water for 20 min; occasional stirring) from 2 g dry soil and filtered. A flame photometer (Coleman) was used to measure sodium (Na) concentrations in the solutions. Conductivity was measured at 25°C on the same extracts with a conductivity bridge.

DISTANCE FROM TRAFFIC CIRCLE. Gates Mills Village sparingly applies a 3:1 mixture of cinders and rock salt to the boulevard, whereas the state of Ohio frequently applies a 100% rock salt mixture to the traffic circle (G. Pasuit, pers. comm.). Accordingly, distance from the traffic circle, a suspected source of high salt input, was recorded.

STATISTICAL ANALYSIS. A correlation matrix was established to determine significance of linear relationships.

RESULTS & DISCUSSION

The means, standard deviations, minimums, and maximums are presented for the 50 sugar maples in

¹Manuscript received 4 December 1987 and in revised form 13 April 1988 (#87-57).

²Present address: HB 1230, Dartmouth College, Hanover, NH, 03755

this study (Table 1). A correlation matrix between some of these data sets is presented in Table 2.

TREE HEALTH INDEX. The means of the incremental growth in radius for the 5 years after 1982 were significantly ($P < 0.001$) lower than the means for the years 1982 and before (Fig. 2). Newbanks and Tattar (1977) showed that decline symptoms and tree ring width in sugar maples correlate strongly. Because of their findings and because visual, subjective observation of crown condition and decline symptoms confirmed it, the index used in this study was considered a valid assessment of tree health. This index did not give an absolute measure of decline but provided a context within which individual tree health could be assessed relative to this specific roadside population.

PROXIMITY TO SALT INPUT SOURCES. The average Na concentration (228 ppm) of the soil next to the boulevard (Table 1) was significantly different ($P < 0.001$) from that (51 ppm) at the reference sites (data not shown). The average conductivity of the soil extracts was 185 μmhos next to the boulevard (Table 1) and 123 μmhos at the reference sites (data not shown). This difference was significant ($P < 0.001$). These data support the findings of Zelazny et al. (1970) and Hutchinson and Olson (1967) who found that salt levels in roadside soils decrease with increasing distance from the salt source. No detectable concentration of salt was found in the snow at the reference sites (data not shown); the average concentration next to the boulevard was 1.70 mg/L (Table 1). With increasing distance from the traffic circle, sap-sugar concentration tended to decrease; tree health tended to increase; snow salt tended to decrease; and conductivity of the soil extract tended to decrease (Table 2). This gradient was probably due to high levels of salt applied to the traffic circle

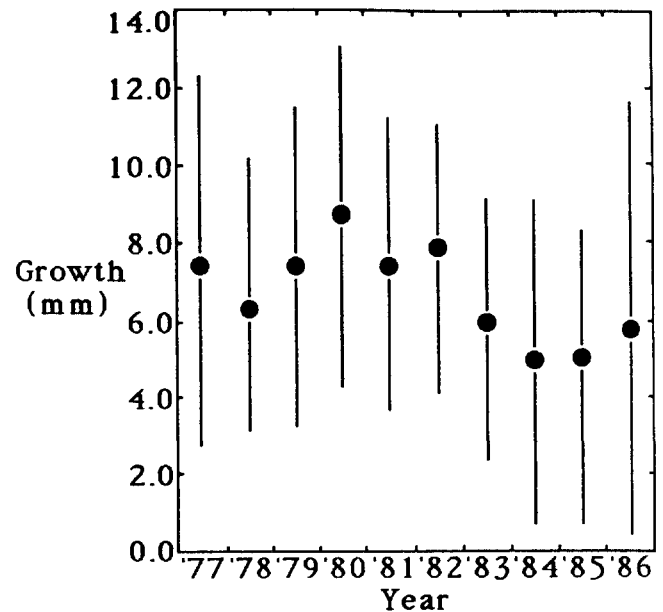


FIGURE 2. Mean growth and range for each year from 50 mature sugar maples.

by the state. The salt may be spread eastward by a slight downward slope of the boulevard and by traffic and snow plows travelling in an eastward direction (Fig. 1).

SAP-SUGAR CONCENTRATION AND SALTS. Significant ($P \leq 0.05$) positive correlations existed between sap-sugar concentration and conductivity, sap-sugar concentration and applied salt, and conductivity and applied salt. The relationship between sap-sugar concentration and conductivity of the soil extract is probably due to the decrease in water uptake normally associated

TABLE 1

Means (\bar{x}), standard deviations (SD), minimums (Min), and maximums (Max) for measurements on mature roadside sugar maples ($N = 50$).

	\bar{x} (SD)	Min	Max
Applied salt (mg/L)	1.70 (0.45)	1.02	3.04
Sap-sugar conc. (%) [*]	4.2 (1.1)	2.7	6.8
Soil Na (ppm)	228 (58)	124	375
Extract conductivity (μmhos)	185 (25)	141	262
DBH (cm)	36.8 (5.6)	25.3	48.5
Mean ring width, '77 to '81 (mm)**	7.45 (1.62)	4.16	10.94
Mean ring width, '82 to '86 (mm)**	5.84 (1.82)	1.90	9.30

^{*} Average of four samples for each tree.

^{**} Average ring width for 5 years indicated.

TABLE 2

Partial correlation matrix from 50 mature sugar maples.

	Applied salt	Sap-sugar conc.	Extract conductivity	Meters from circle
Tree health index	-0.236	-0.516***	-0.253	0.522***
Meters from circle	-0.709***	-0.540***	-0.438**	
Sap-sugar conc.	0.322*		0.320*	

* $P \leq 0.05$

** $P \leq 0.01$

*** $P \leq 0.001$

with increased salinity (Hayward and Spurr 1944, Ehlig et al. 1968). Holmes (1961) showed that in soil with more salts applied, sugar maples had higher concentrations of salt in the twigs and leaves. Zelazny et al. (1970) showed that silver maples (*Acer saccharinum*) in saltier soil increased uptake of Na^+ and Cl^- into their twigs and leaves. These salts, once inside the tree (Leggett 1968), could affect internal mechanisms of water uptake. Tyree (1983) suggested that the crystallization of sap during the water recharge stage at night at least partially explains water uptake. If the freezing point of the sap is depressed by salt, water uptake in the sugar maple could decrease. Even if internal mechanisms of water uptake are not affected in the Gates Mills maples, increased osmotic pressure in soil water due to soil salinity may lower the overall water uptake of the trees (Prior and Berthouex 1967), which leads to a concentration of sap-sugar in spring (Cortes and Sinclair 1985, Milburn and Zimmerman 1986).

TREE HEALTH AND SALTS. The reported inverse relationship between tree health and salts in the soil in other studies is due to several factors. Both Na^+ and Cl^- have toxic effects on sugar maples (Holmes 1961, Holmes and Baker 1966, Lacasse and Rich 1964, Shortle et al. 1972). The salt, as described above, reduces water uptake of trees and symptoms of decline mimic those of drought. Sodium sometimes causes potassium (K) deficiency, since it restricts K uptake (Guttay 1976). Salt is also toxic to the endomycorrhizae on the roots which supply the tree with phosphorus (P). Reduced P levels and reduced numbers of mycorrhizae have been observed in declining trees (Guttay 1976). Sodium dominates the cation exchange sites of the soil as well, which causes other cations such as K and calcium (Ca) to go into solution and leach out of the soil (Holmes 1961). The increased Na on the exchange sites also breaks down soil structure (Holmes 1961, Hutchinson and Olson 1967) which decreases permeability and water holding capacity of the soil. All of these factors may contribute to decline in health of maples. Although this study did not find a significant correlation between soil salts and tree health, as in other studies, growth did tend to decline closer to the traffic circle where more salt was applied.

TREE HEALTH AND SAP-SUGAR CONCENTRATION. Highly significant ($P \leq 0.001$) correlations were found between sap-sugar concentration and tree health. Three possible explanations of these relationships were considered. First, trees could compensate for poor health by producing more concentrated sap. Second, increased sugar concentration could cause a decrease in the growth of the trees or, although the sap is more concentrated, there may be less sap volume and less total sugar. Carroll et al. (1983) observed lower concentrations of root starch in declining trees which seems to suggest less overall sap-sugar in the spring. Third, the relationship between sap-sugar concentration and tree health may not be direct, but instead may be due to each measurement's relationship to some other factor such as soil salinity.

CONCLUSION

Sap-sugar in declining roadside sugar maples tends to be more concentrated than in healthy sugar maples. It

is likely that salt plays a crucial role since, in the present study, the salinity of the soil tended to increase with the increase in sap-sugar concentration. The implications of this for maple syrup producers is not certain. Further research is needed to determine the effects of salts on the total sugar yield and the sap volume output over a season. The results of this study are important for research on translocation and water uptake of trees as factors in tree pathology, since sap-sugar concentration and tree health seem to be related.

ACKNOWLEDGMENTS. This study was made possible by the Strnad Fellowships at University School. Grateful acknowledgments are made to P. Barnes and T. Harmon for advice on the project; A. J. Friedland for valuable review; M. Stolar for help with statistics; P. Olynyk and Cleveland State University for the use of the flame photometer and conductivity meter; and G. Pasuit of Gates Mills Village for allowing work on the trees.

LITERATURE CITED

- Carroll, J. E., T. A. Tattar, and P. M. Wargo 1983 Relationship of root starch to decline of sugar maple. *Plant Dis.* 67: 1347-1349.
- Cortes, P. M. and T. R. Sinclair 1985 The role of osmotic potential in spring sap flow of mature sugar maple trees (*Acer saccharum* Marsh). *J. Exp. Bot.* 36: 12-24.
- Ehlig, C. F., W. R. Gardner, and M. Clark 1968 Effect of soil salinity on water potentials and transpiration in pepper (*Capsicum frutescens*). *Agron. J.* 60: 249-253.
- Guttay, A. J. R. 1976 Impact of deicing salts upon the endomycorrhizae of roadside sugar maples. *Soil Sci. Soc. Am. J.* 40: 952-954.
- Hayward, H. E. and W. B. Spurr 1943 Effects of osmotic concentration of substrate on the entry of water into corn roots. *Bot. Gaz.* 105: 152-164.
- Holmes, F. W. 1961 Salt injury to trees. *Phytopathology* 51: 712-718.
- and J. H. Baker 1966 Salt injury to trees. II. Sodium and chloride in roadside sugar maples in Massachusetts. *Phytopathology* 56: 633-636.
- Hutchinson, F. E. and B. E. Olson 1967 Relationship of road salt applications to sodium and chloride ion levels in the soil bordering major highways. *Highway Resource Record* 193: 1-7.
- Lacasse, N. L. and A. E. Rich 1964 Maple decline in New Hampshire. *Phytopathology* 54: 1071-1075.
- Leggett, J. E. 1968 Salt absorption by plants. *Ann. Rev. Plant Physiol.* 19: 333-346.
- Milburn, J. A. and M. H. Zimmerman 1986 Sapflow in the sugar maple in the leafless state. *J. Plant Physiol.* 124: 331-344.
- Newbanks, D. and T. A. Tattar 1977 The relationship between electrical resistance and decline symptoms in *Acer saccharum*. *Can. J. For. Res.* 7: 469-475.
- Prior, G. A. and P. M. Berthouex 1967 A study of salt pollution of soil by highway salting. *Highway Resource Record* 193: 8-21.
- Shortle, W. C. and A. E. Rich 1970 Relative sodium chloride tolerance of common roadside trees in southeastern New Hampshire. *Plant Dis. Repr.* 54: 360-362.
- , J. B. Kotheimer and A. E. Rich 1972 Effect of salt injury on shoot growth of sugar maple, *Acer saccharum*. *Plant Dis. Repr.* 56: 1004-1007.
- Stockeller, J. H. and S. Weitzman 1960 Infiltration rates in frozen soils in northern Minnesota. *Proc. Soil Sci. Soc. Amer.* 24: 137-139.
- Tyree, M. T. 1983 Maple sap uptake, exudation, and pressure changes correlated with freezing exotherms and thawing endotherms. *Plant Physiol.* 73: 277-285.
- Wester, H. V. and E. E. Cohen 1968 Salt damage to vegetation in the Washington, D.C. area during the 1966-67 winter. *Plant Dis. Repr.* 52: 350-354.
- Westing, A. H. 1966 Sugar maple decline: an evaluation. *Econ. Bot.* 20: 196-208.
- 1969 Plants and salt in the roadside environment. *Phytopathology* 59: 1174-1181.
- Zelazny, L. W., R. E. Blaser and R. E. Hanes 1970 Effects of deicing salts on roadside soils and vegetation. *Highway Resource Record* 335: 9-12.